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Lessons Learned Converting an Application for Determining Armor Health from the Laboratory to TRL6

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14. ABSTRACT
The Sensor Enhanced Armor (SEA) team has developed a method and algorithm for determining the health of Stryker ceramic armor panels. This method has been described in detail in several previous reports which are listed in the references. The method was developed and tested using a laboratory computer; however, this computer is not suitable for use in the field due to its size, weight and electrical requirements. This report documents the efforts to port the system to a small portable computer, (patent pending on method).

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Abstract

The Sensor Enhanced Armor (SEA) team has developed a method and algorithm for determining the health of Stryker ceramic armor panels. This method has been described in detail in several previous reports which are listed in the references. The method was developed and tested using a laboratory computer; however, this computer is not suitable for use in the field due to its size, weight and electrical requirements. This report documents the efforts to port the system to a small portable computer, (patent pending on method).

Introduction

One of the goals of the SEA team in this preliminary effort for PM Stryker is to develop a small portable hand tester which can be easily used by soldiers in the field to test the health of armor panels. Many first principle technical methods are developed in the laboratory using powerful resources. They typically include high performance computers, signal generators, and 16 bit A/D converters. These resources are typically not available in a portable system. This report documents our efforts to develop a fieldable system based on determining which characteristics of the laboratory system were critical to the method, and what hardware and software requirements could be compromised to achieve the goal of producing a fieldable system that produces acceptable results as compared to the laboratory system. [†]

[†] Disclaimer: Reference herein to any specific commercial company, product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or the Department of the Army (DoA). The opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or the DoA, and shall not be used for advertising or product endorsement purposes.

In this report the authors discuss the various hardware and software components that were used in the laboratory system and how it was determined what the minimum requirements were for the portable system. In some cases simulation was used, in other cases a microprocessor was used that the electronics group had previously used.

A/D Converter

The system developed for testing armor health depends upon placing transducers on the armor plate. A signal function generator is used to generate sine waves of various frequencies which are then applied to the transducers. The signals from opposing transducers are then collected by an A/D converter which converts the analog signal to a digital signal. The A/D converter in the laboratory machine has 12 bits of precision which means that it can distinguish between 2^{12} or 1024 distinct values. The microprocessor that was suggested for the project only has an 8 bit A/D converter which means it can distinguish between 2^{8} or 256 distinct values. To determine if the precision of the 8 bit A/D converter would be accurate we decided to do a simulation. The idea was to collect data at 12 bits of precision and then reduce it to 8 bits of precision in a simulation. After that we could compare the results from the 8 bit data with that of the 12 bit data. The results of the simulation are presented in the graphs below.
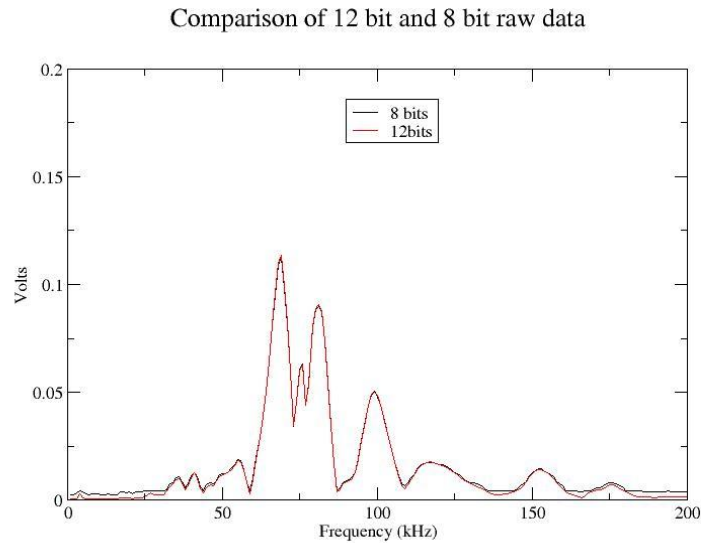
Comparison of 12 bit and 8 bit raw data

Figure 1 Raw Data Comparison (12 bit and 8 bit)

Figure 1 shows that the graph of the simulated 8 bit data is very close to that of the 12 bit actual data. The minor differences occur mostly at the very low and very high frequencies and the frequencies are not critical to the method. Further simulations showed the effects of using an A/D converter with substantially lower resolution. We did a simulation with a 3 bit converter, and the results of this simulation are shown in Figure 2 below. While this may seem extreme since all micro computers that have an A/D converter typically have at least a 6 or 8 bit converter, if the range for the converter is not set properly many bits of precision can be lost. For example if an 8 bit A/D converter is set for the range -1.0 to +1.0 volts the output of the converter will have 256 values between -1.0 and +1.0. If the actual experimental data is between -0.125 and +0.125 there will only be 256/8 values or 32 values in this range. This would make the 8 bit converter a 5 bit converter since $2^5 = 32$.
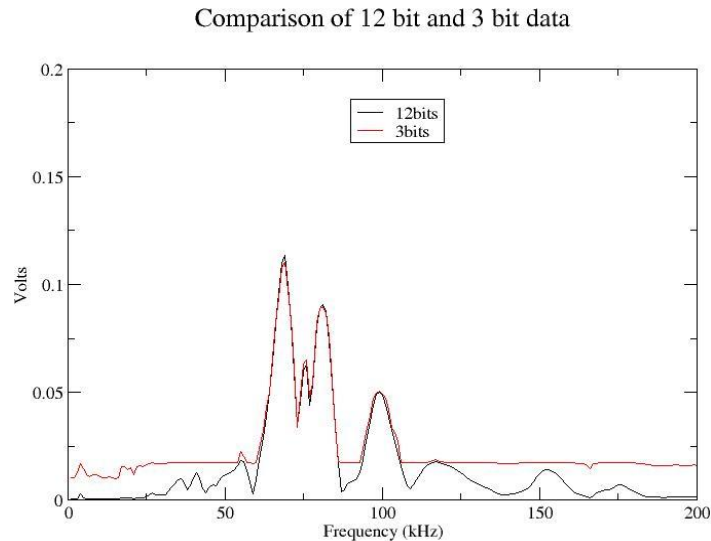
Comparison of 12 bit and 3 bit data

Figure 2 Raw Data Comparison (12 bit and 3 bit)

Figure 2 compares the 12 bit with the 3 bit simulated data. While there seems to be relatively good agreement between the 2 data sets for frequencies between 60 and 90 kHz, it is clear from the graph that the two curves are quite different, and it doesn't seem that the 3 bit A/D converter would be adequate.

Frequency Response

The laboratory computer was able to generate sine waves from 1 to 200 kHz by 1 kHz increments. Due to limitations in the microprocessor it was not capable of generating all these frequencies. It could generate all the frequencies up to 54 kHz, but after that there are gaps in what it could do. For example it couldn't do 55 kHz, 58 kHz and 60 k. The gaps grew larger as the frequencies increased. So for example it could do 138 kHz and 147 kHz, but nothing in between these two frequencies. (This limitation will be removed in the next version of the system.) Although the laboratory system collects the

system response from all the frequencies from 1 to 200 kHz, the main response of the

Stryker panels occurs below 54 kHz, so it didn't seem that the missing frequencies would

prevent the microprocessor system from functioning properly. Figure 3 below shows an

image of the fingerprint file. The non-zero frequencies in this file are used to determine if

a Stryker armor plate has been damaged. As is seen in Figure 3 the non-zero values in the

fingerprint file occur at less than 50 kHz, so the gaps above 54 kHz have little effect on
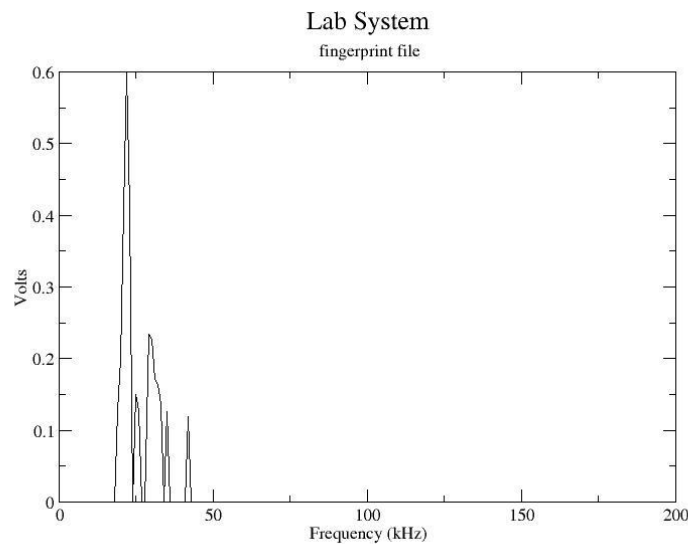
the results.

Figure 3 Database file from the Lab System

Figure 4 shows a comparison between the fingerprint files from the lab system and the

micro system. Only the frequencies between 1 and 50 kHz are shown since those outside

this range are 0. The fingerprint file is derived by averaging the responses of the system

at each frequency over the range from 1 to 200 kHz. The assumption is that while each

individual run has random errors due to noise in the system, these errors should have a

mean value of 0, so averaging them should tend to remove them. The other concept is

that of fundamental frequencies; the armor plate tends to vibrate much more at some

frequencies than at others. In fact by sorting the frequencies by magnitude of response,

we can usually get 90% of the total response from 25% of the frequencies or less. In the

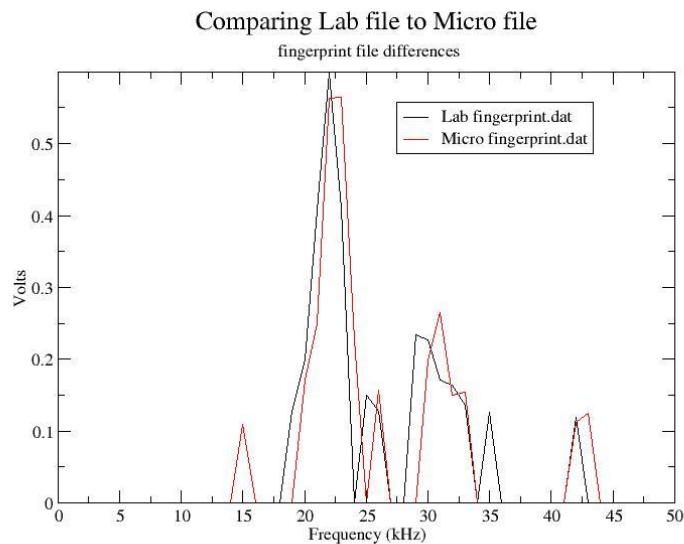example in Figure 3 only 14 frequencies or 7% of 200 were needed.

Figure 4 Comparison of Fingerprint Files

As Figure 4 shows the fingerprint files are quite similar although not exactly the same.

By inspecting Figure 4 it is not clear if the two systems will give the same response or

how comparable the responses will be. It was decided that the best way to compare the

two systems was to collect data from both systems (the lab system and the micro system)

and process the results.

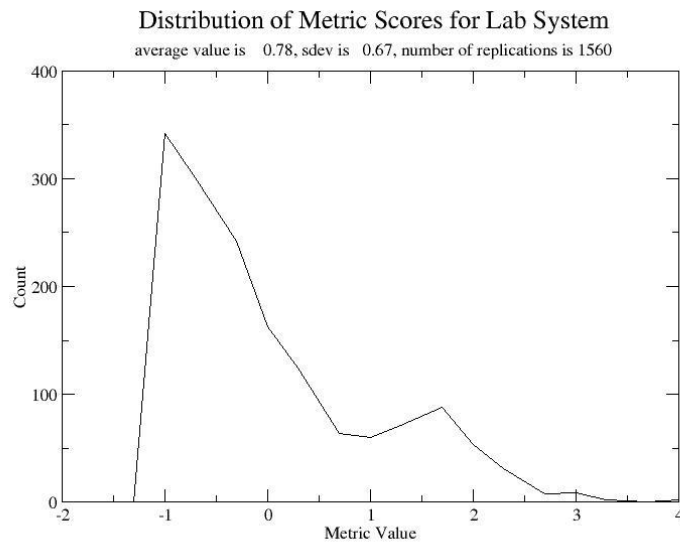**Final Comparison of the Laboratory System and the Portable System**

Distribution of Metric Scores for Lab System

average value is   0.78, sdev is   0.67, number of replications is 1560

Figure 5 Score Distribution for Lab System

Distribution of Metric Scores for micro system

average value is   0.86, sdev is   1.05, number of replications is 931
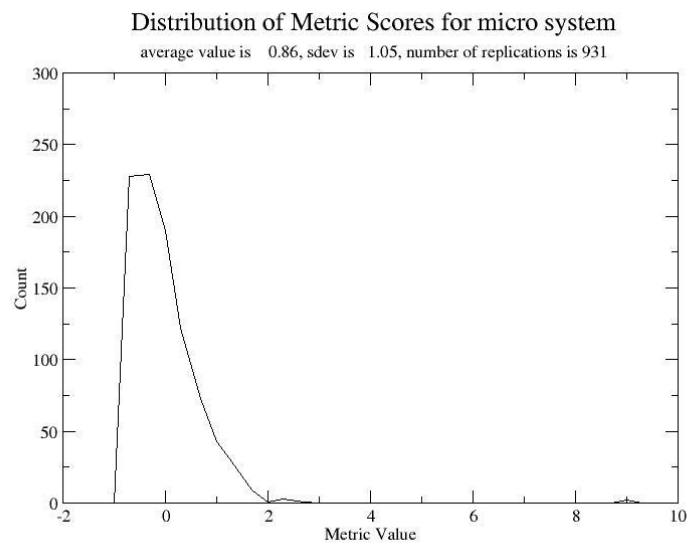
Figure 6 Score Distribution for Micro System

The graphs in Figures 5 and 6 above give an idea of the capability of both systems. These

graphs represent the deviations in the response from any particular run from the "ideal

response". Both curves approximate a normal distribution in shape. This is to be expected because the fingerprint file is defined by taking an average. The following table summarizes the major difference between the two systems.

System	# of runs	Average Value	Standard Deviation	Maximum Deviation
Lab	1560	0.78	0.67	3.9
Micro	931	0.86	1.05	9.7

Table 7 comparing the Lab and Micro Systems

As the table shows the results are similar. The micro system has a standard deviation which is about 50% higher than lab system; however, it is still small for both systems. The maximum deviation of 9.7 for the micro system is much higher than the 3.9 value for the lab system; however, this may be due to bumping the armor plate during data collection. In any case, it only occurred 2 times out of 900 tests.

PCB Layout

The process of miniaturizing the bench top laboratory equipment was no small task. It was important to decide what factors were deemed essential and which features were optional. Once that decision was made, the process of selecting components could begin. After testing the circuit on a prototype board the design was transferred to National

Instruments Multisim software package which would serve as the final circuit configuration. Figure 8 depicts the final circuit schematic.
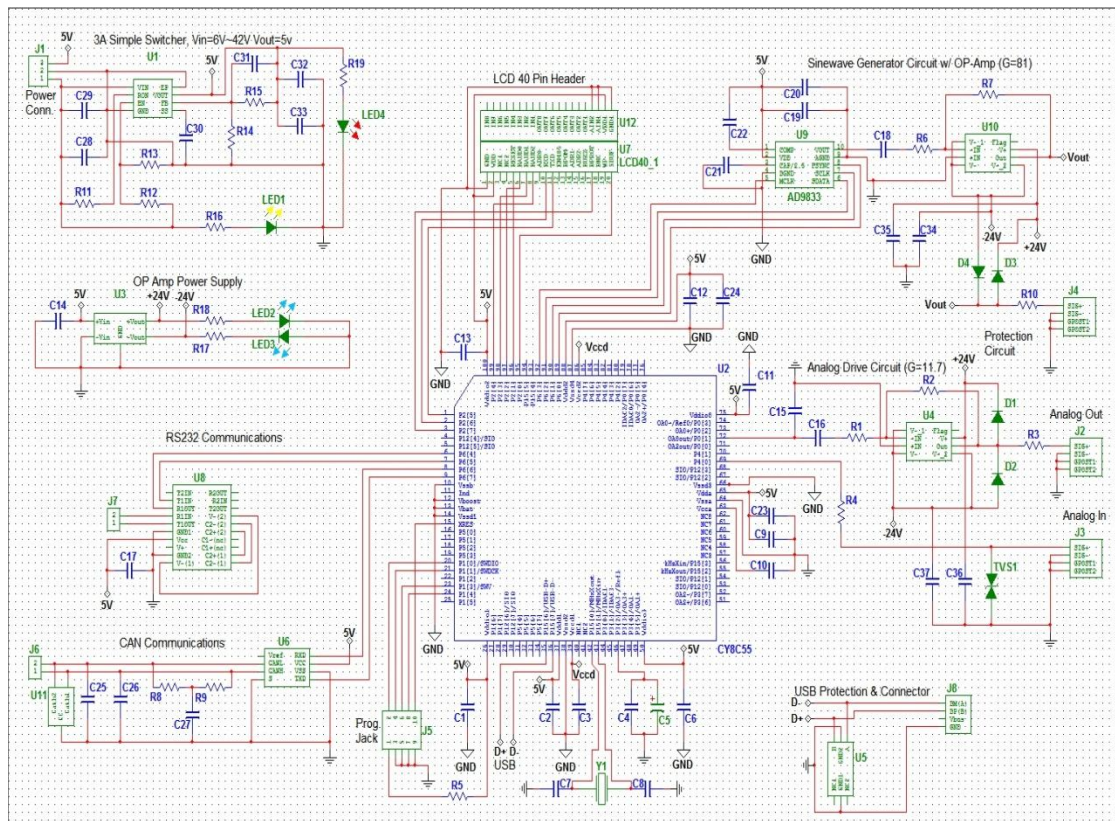

Figure 8 – U-SEA Circuit Schematic

Programmable System on a Chip (PSoC)

The Cypress PSoC5 microcontroller is a unique device in the fact that it is a self-configurable integrated circuit. The ability to accomplish this means that the circuit has greater flexibility without having to manufacturer a new PCB each time a change in hardware is required. The design environment, PSoC Creator, allows the designer to drag and drop commonly used components into the design and assign an I/O pin. Figure 9 shows the PSoC Creator layout that was used in designing the U-SEA project.
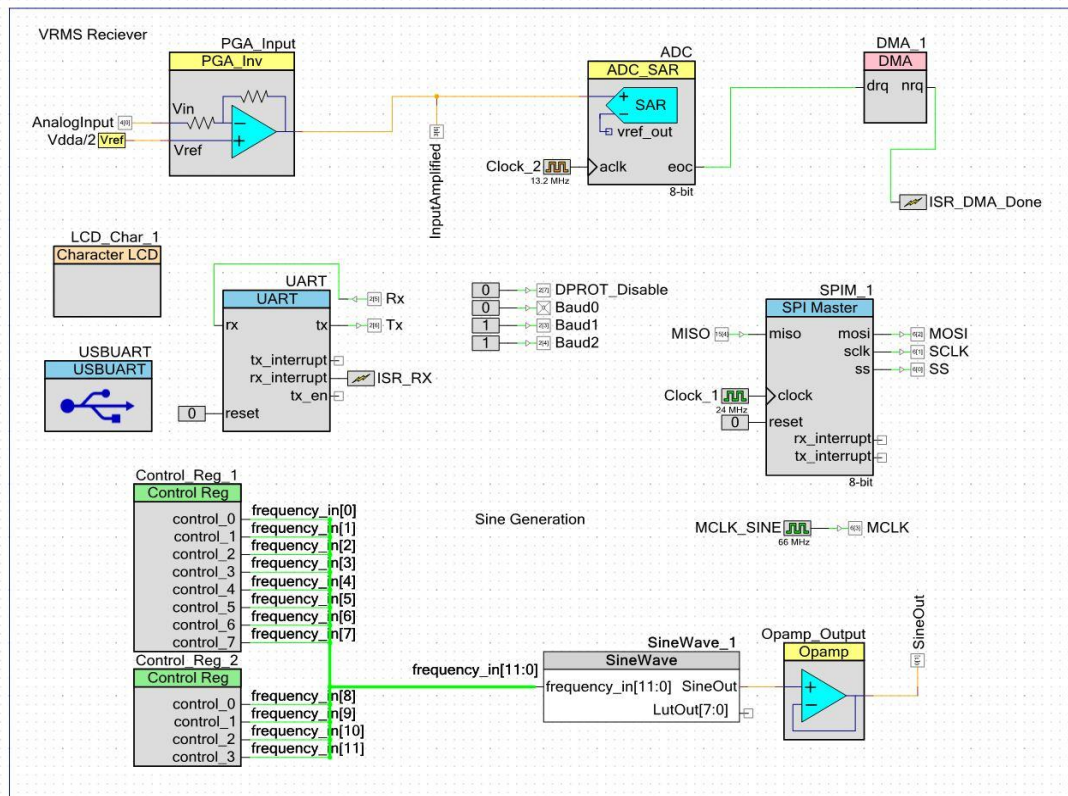
Figure 9 – PsoC Creator Top Level Component Layout

Conclusion

The authors have transitioned a laboratory technique and device to something that could
be portable and used in the field. Today's microcontrollers are much more powerful than
those of even a few years ago. Microcontrollers sometimes lack the flexibility and
debugging tools for developing standard computer applications. However, once an
application has been developed, it can often be ported to the microcontroller as long as
adequate safeguards are taken to make sure using the microcontroller doesn't
compromise system integrity. Simulations can be used to determine which system
components can be downsized without harming the basic system functionality.

References

[1] Thomas J. Meitzler, Thomas Reynolds, Samuel Ebenstein and Gregory Smith,” Evaluating the Stability of a Metric for Determining the Health of Armor Plates”, M.E., Vol. 69, No. 5, May 2011, pp. 597–601.

[2] Thomas J. Meitzler, Gregory Smith, Michelle Charbeneau, Euijung Sohn, Mary Bienkowski, “Ivan Wong and Allen H. Meitzler, “Crack Detection in Armor Plates Using Ultrasonic Techniques”, M.E., Vol. 66, No. 6, June 2008, pp. 555-559.